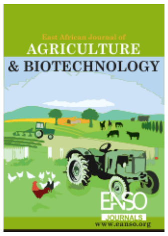

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Original Article

Assessing the Unfulfilled Promises of Agroforestry and Conservation Agriculture as Climate-Smart Solutions for Food Security in Kenya, Tanzania, Uganda, and Zimbabwe

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Agroforestry, Climate-Smart Agriculture, Conservation Agriculture, Food Security, Smallholder Farmers, Soil Conservation.

ABSTRACT

This study assessed the unfulfilled promises of agroforestry (AF) and conservation agriculture (CA) as climate-smart agriculture (CSA) practices in Kenya, Tanzania, Uganda, and Zimbabwe. Despite their potential for carbon sequestration, soil conservation, and enhanced food security, empirical evidence of their effectiveness remains fragmented, particularly at larger scales. The research aimed to evaluate the ecological functions of AF and CA, their impact on smallholder farming systems, and the socio-economic barriers to their adoption. Key objectives include understanding their contributions to carbon sequestration, soil health, and climate resilience, as well as identifying strategies to enhance their scalability and effectiveness. The study employed a systematic literature review, focusing on peer-reviewed articles published between 2021 and 2024. Boolean operators were used to search databases like Google Scholar, Web of Science, and Scopus. Inclusion criteria prioritised studies on AF and CA as CSA practices, conducted in the specified countries, and available in English. The review process involved title and abstract screening, full-text analysis, and final selection based on relevance and data quality. Findings revealed that AF and CA show significant potential for improving environmental sustainability and farm productivity, particularly in enhancing soil fertility and carbon sequestration. However, their adoption is hindered by financial constraints, limited access to credit, and socio-economic disparities among farmers. Mixed results were observed in crop yield improvements, with some regions reporting positive outcomes while others showed negligible benefits. The study highlights the need for tailored interventions, supportive policies, and institutional capacity-building to overcome these barriers. In conclusion, AF and CA can contribute to climate resilience and food security, but their success depends on integrating innovative techniques with organic matter management and leveraging social structures for mobilisation. Recommendations include scaling up these practices through commercialisation, resource availability, and knowledge dissemination. Future research should focus on refining models for small land sizes, addressing labour constraints, and employing participatory approaches to ensure sustainable adoption and effectiveness in sub-Saharan Africa.

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INTRODUCTION

Numerous studies have highlighted the potential of agroforestry and conservation agriculture as effective climate-smart agricultural (CSA) practices, particularly in their role in carbon sequestration and overall ecosystem enhancement (Zomer et al., 2022; Ghale et al., 2022; Singh et al., 2024). These practices have been widely promoted as solutions for mitigating climate change by reducing carbon emissions and enhancing soil health. However, despite the widespread claims, empirical evidence on their actual effectiveness remains fragmented and inconclusive, particularly at larger landscape scales (Zahoor et al., 2021; Koutika et al., 2021). The focus of existing research has primarily been on small-scale subsistence agriculture, with limited assessments of its scalability and impact beyond micro-level case studies. Moreover, studies predominantly examine tree-based agroforestry systems while other forms of agroforestry remain underexplored (Dev et al., 2022; Gautam et al., 2022).

The difficulty in assessing the real impact of agroforestry and conservation agriculture at landscape scales stems from their interaction with various land-use transitions, habitat types, and agricultural sectors (Arshad et al., 2021). These complexities make comprehensive evaluations challenging. Additionally, general discussions about their carbon sequestration potential often lack specificity concerning scale and land-use intensity. Consequently, evidence on the extent to which these practices fulfil their climate-smart potential remains sparse. Their optimal spatial configuration and socio-economic feasibility in smallholder agriculture contexts are yet to be fully understood. Sub-Saharan Africa (SSA), including countries such as Kenya, Tanzania, Uganda, and Zimbabwe, faces significant agricultural challenges due to increasing climate variability. Rising temperatures and shifting precipitation patterns are projected to reduce crop yields, particularly in tropical regions (Yang et al., 2021; Cos et al., 2022).

In East Africa, delays in the onset of rainy seasons have reduced rainy days, and more extreme weather events have been observed. Projections indicate a temperature increase of 1 to 3.3 °C by the 2050s, which will have severe implications for crop and

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livestock production, water availability, and soil health (You et al., 2021; Henderson et al., 2022). Staple crop systems, including maize-legume rotations and banana-based agroecosystems, are expected to experience significant productivity declines under these changing climatic conditions. Given that forestry, energy, and agriculture collectively contribute substantial greenhouse gas emissions in Eastern Africa (Jain et al., 2022), solutions that enhance carbon sequestration while maintaining agricultural productivity are crucial. The adverse effects of climate change on agricultural productivity and profitability threaten livelihoods and exacerbate poverty levels in SSA. Increased climate variability raises concerns about soil erosion, land degradation, and resource depletion, necessitating the adoption of sustainable land management strategies.

Agroforestry and conservation agriculture have been promoted as adaptive solutions, offering multiple co-benefits such as increased resilience to pests and diseases, improved soil conservation, enhanced microclimate regulation, and better air quality. These practices also contribute to food security by stabilising yields despite erratic weather conditions (Henderson et al., 2022; Allan et al., 2023). However, their actual contributions to climate adaptation and mitigation remain under-investigated, particularly in the context of smallholder farmers who operate under diverse socio-economic and environmental constraints. Agriculture in SSA is increasingly vulnerable to climate-induced risks, necessitating a shift towards more sustainable and resilient production systems. While significant efforts have been made to promote CSA adoption, empirical evidence on its actual benefits remains scarce, especially concerning agroforestry and conservation agriculture practices. The effectiveness of these practices in enhancing soil fertility, improving carbon sequestration, and supporting ecosystem services has not been systematically evaluated at the farm level. Furthermore, the pathways through which smallholder farmers adopt CSA and the challenges they face in implementing these practices require further investigation. Current food production levels in SSA are insufficient to meet growing demand, leading to increased dependence on processed food imports. Low agricultural productivity is primarily driven by declining soil fertility, poor resource management, and climate variability. Despite the promotion of conservation agriculture and agroforestry as sustainable alternatives, their widespread adoption remains limited. Understanding the barriers to their implementation and identifying strategies for optimising their benefits is crucial for enhancing food security and climate resilience in the region.

This study aimed to evaluate the extent to which agroforestry and conservation agriculture practices fulfil their promises as climate-smart agricultural strategies in Kenya, Tanzania, Uganda, and Zimbabwe. The research focused on assessing the ecological functions of these practices, including carbon sequestration, soil conservation, and their overall impact on agroecosystem stability, productivity, and resilience under smallholder farming conditions. Additionally, the study seeks to identify the challenges that smallholder farmers face in adopting these practices and explore the measures needed to maximise their benefits. Specifically, the research will address the following key questions: To what extent do agroforestry and conservation agriculture contribute to carbon sequestration and soil conservation in smallholder farming systems? How do these practices influence food security and resilience to climate change in the study regions? What socio-economic and policy factors affect the adoption and sustainability of agroforestry and conservation agriculture among smallholder farmers? What strategies can enhance the effectiveness and scalability of these practices in addressing climate change adaptation and mitigation? By addressing these questions, this

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study aims to generate insights that can inform policy decisions, guide extension services, and support smallholder farmers in effectively integrating agroforestry and conservation agriculture into their farming systems. Ultimately, the findings will contribute to a better understanding of how these practices can be optimised to enhance food security, improve ecosystem services, and build resilience against climate change in Eastern and Southern Africa.

LITERATURE REVIEW

The need to strengthen the adaptive capacity of agricultural systems has gained increasing attention as part of broader global, regional, national, and local strategies to address climate change. This concept is frequently framed within the discourse of "climate-smart agriculture" (CSA). However, the promotion of practices such as agroforestry and conservation agriculture as means to enhance agricultural resilience is not a recent development. These practices have long been advocated in various countries as solutions to support sustainable farming systems (Park et al., 2022; Fahad et al., 2022).

Recently, this expectation has been amplified by stakeholders pushing for the integration of CSA into national policies. This aligns with the broader narrative that CSA can contribute to long-term food security while preserving and improving the livelihoods of those most vulnerable to climate variability and uncertainty. Nonetheless, the extent to which these claims reflect reality remains debatable, as they are often presented with an overly optimistic outlook (Santiago-Freijanes et al., 2021; Rosati et al., 2021; Rodenburg et al., 2021; Mazhar et al., 2021).

Although agroforestry and conservation agriculture are frequently promoted as solutions for "greening" agriculture, their large-scale adoption remains constrained. Farmers, government agencies, and civil society often have limited influence over the expansion of these practices, not necessarily due to a lack of interest but rather due to systemic barriers (Castle et al., 2021; Choden & Ghaley, 2021; Raihan, 2023). Additionally, governance reforms within the agricultural sector have, in some cases, weakened institutional support for these practices, placing their future sustainability at risk. For CSA to be effectively implemented, both international donors and national governments must take deliberate steps to establish an enabling policy environment that fosters long-term adoption. Furthermore, alternative approaches that align more closely with national development goals, poverty reduction strategies, and pathways toward low-carbon economic growth should be explored, ensuring that agricultural transformation remains both inclusive and sustainable.

Key Concepts of Agroforestry and Conservation Agriculture

Agroforestry and conservation agriculture are modern approaches to agricultural systems that emphasise environmental benefits. Conservation agriculture is typically defined in three ways: (a) as a farming method that minimises soil disturbance, ensures continuous soil cover, and incorporates crop rotation; (b) as a set of guiding principles; and (c) as an alternative to conventional agricultural models based on scientific and technological advancements. Similarly, agroforestry integrates trees into agricultural landscapes to prevent deforestation while producing food, fuel, and timber.

This practice also supports soil conservation, biodiversity, and other ecological services. In Africa, traditional agroforestry systems, often characterised by complex indigenous techniques, are gradually being replaced by fast-growing tree species compatible with commercial agriculture. Global discussions on climate-smart agriculture frequently highlight the role of agroforestry and conservation agriculture in promoting sustainable agricultural practices (Udawatta et al., 2021; Jose &

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Udawatta, 2021; Pantera et al., 2021; Castle et al., 2021; Rosati et al., 2021; Adedibu, 2023; Fatima et al., 2024).

Effectiveness of Agroforestry and Conservation Agriculture as CSA Practices

Research examining the effectiveness of agroforestry and conservation agriculture in sub-Saharan Africa presents varied results, with limited studies focusing on arid regions where climate-smart agriculture is most needed (Rehman et al., 2022; Notaro et al., 2022; Saikanth et al., 2023). Findings from Kenya, Malawi, and Zimbabwe indicate that conservation agriculture generally enhances cereal and legume yields. In Western Kenya, this yield increase was primarily observed in farms exceeding three hectares. Malawi's southern region exhibited improved drought tolerance and higher maize yields under conservation agriculture practices (Ngalande, 2021; Mwiinga, 2021; Murindangabo et al., 2021; Kimathi, 2023).

In Tanzania, positive yield outcomes were observed under normal rainfall conditions, though results were inconsistent during drought periods. Studies from Tanzania, Malawi, and Mozambique suggest that conservation agriculture could enhance drought-resilient dairy feeding systems, yet concerns remain regarding reduced fodder yields when prioritising food crops. The benefits of conservation agriculture are not universally consistent, as some semi-arid regions in Malawi and Tanzania showed negligible yield improvements (Mupangwa et al., 2021; Ngoma et al., 2021; Mbanyele et al., 2022). Similarly, in Kenya, labour-intensive practices such as manual labour and animal traction sometimes led to reduced profitability. Socioeconomic disparities also influence adoption rates, with wealthier farmers more likely to benefit than lower-income groups.

Most research on agroforestry and conservation agriculture has focused on farm-level impacts, highlighting the role of land use and soil management in mitigating climate change effects. These practices contribute to soil health by enhancing organic matter and improving soil structure. While conventional farming has depleted soil nutrients, agroforestry systems improve soil fertility through nitrogen fixation and nutrient recycling. Globally, agroforestry is recognised for its scalability and potential to support climate adaptation (Koutika et al., 2021; Fahad et al., 2022; Rawat et al., 2022; Kaur et al., 2023).

Conservation agriculture, emphasising minimal soil disturbance, has been linked to better soil structure and infiltration rates. However, its role in building soil carbon stocks compared to agroforestry and small-scale agroecological systems in developing nations remains unclear (Kiboi et al., 2021; Muthoni et al., 2021). Despite evident environmental advantages, both agroforestry and conservation agriculture have limitations. There is a lack of extensive research on their resilience to extreme weather events such as heavy rainfall and flooding. Additionally, agroforestry's carbon sequestration potential may reach a saturation point beyond which no additional benefits are gained (Reicosky & Kassam, 2021; Bohoussou et al., 2022; Cárceles et al., 2022; Das et al., 2022; Francaviglia et al., 2023).

Overview of CSA, Agroforestry, and Conservation Agriculture

Climate-smart agriculture (CSA) integrates sustainable agricultural practices with environmental stewardship to enhance productivity, mitigate greenhouse gas emissions, and support adaptation to climate change. This approach promotes resource-efficient strategies, with agroforestry and conservation agriculture recognised as key interventions. Agroforestry contributes to sustainable land use by preserving soil, water, and vegetation, while conservation agriculture complements it through minimal tillage, moisture conservation, and reduced reliance on

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chemical inputs (Jose et al., 2022; Keprate et al., 2024; Jumiyati & Frimawaty, 2024; Robert & Peter, 2024).

Agroforestry offers ecological and socio-economic benefits by enhancing environmental stability, economic resilience, and social capital. CSA, agroforestry, and conservation agriculture share common environmental and cultural dimensions, with overlapping benefits such as soil enrichment, biodiversity conservation, and ecological sustainability. Research suggests that integrating indigenous knowledge with agroforestry, conservation agriculture, and agroecological practices can strengthen climate adaptation efforts. Understanding local environmental and socio-economic contexts is crucial before implementing these strategies (Rozaki et al., 2021; Xu et al., 2021; Smith et al., 2022; Cerca et al., 2022; Egli et al., 2023).

Benefits and Limitations of Agroforestry and Conservation Agriculture in Climate Change Mitigation

Benefits of Agroforestry and Conservation Agriculture

Agroforestry enhances biodiversity, soil fertility, and agricultural resilience across multiple scales. Integrating trees with crops and livestock sustains agricultural biodiversity by supporting pollinators, birds, and other wildlife (Tsufac et al., 2021; Marques et al., 2022). Agroforestry systems, particularly those on forest edges, tend to have higher biodiversity levels than monoculture systems. While African agroforestry systems are often perceived as less diverse, they still provide ecological benefits (Udawatta et al., 2021; Suárez et al., 2021; Rosati et al., 2021; Fahad et al., 2022).

Conservation agriculture enhances cropping system sustainability by improving soil health and increasing biodiversity. It reduces soil erosion, enhances organic matter, optimises water retention, and minimises reliance on synthetic fertilisers and pesticides. These practices also facilitate rural technology transfer, fostering an enabling environment for sustainable agriculture (Shah et al., 2021; Viguier et al., 2021; Kumar et al., 2021). Conservation agriculture seeks to mimic natural ecosystems while maintaining agricultural productivity. However, global pressures such as urbanisation, food demand, and climate change necessitate broader systemic adaptations. Conservation agriculture is one approach that, when integrated into holistic farming strategies, can support resilient and sustainable agricultural production (Hermans et al., 2021; Cárceles et al., 2022; Francaviglia et al., 2023).

Review of Existing Studies on AF and CA in Tanzania, Uganda, and Zimbabwe

Tanzania, Uganda, and Zimbabwe are some of the African countries in which studies on AGFOR/CA have been conducted. In Tanzania, some studies have been carried out in the northeastern, northern, and southern highlands, and the eastern and central zones of the country. On the other hand, the southwestern, central, and western parts of Tanzania were not covered by the studies. In Uganda, most of the work on AGFOR/CA has been carried out in the eastern region. However, the studies did not cover western Uganda. In Zimbabwe, most of the empirical evidence was generated in the northern and eastern regions. The rest of the country was not covered by empirical work on AGFOR and CA. Studies on the possible upscaling and promotion of climate-smart technologies in agriculture are ongoing in the country.

AGFOR/CA interventions can be site-specific; as a result, evidence and effects cannot be generalised from one agroecological zone to another. For example, research findings wrap across both agroecological zones and crops relevant to the local level (e.g., maize, bananas in Uganda and Tanzania, groundnut and pigeon pea in Tanzania and

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Zimbabwe) (Udawatta et al., 2021; Fahad et al., 2022). Existing knowledge from Kenya, Tanzania, Uganda, and Zimbabwe shows that economic benefits are complex and vary at the farmer level, combining market access and crop performance. Socio-economic benefits resulting from AF and CA adoption have also been studied. Studies have revealed that socio-economic benefits have been driven by the household characteristics of the AF adopters. Environmental benefits have been studied in Zimbabwe and Tanzania. Research has focused on soil fertility restoration, erosion control, and above-ground benefits, such as carbon sequestration (Suárez et al., 2021; Rosati et al., 2021). This knowledge has shown an enhancement of soil infiltration, increased yield, and reduced soil erosion in AF-CA versus conventional farmers' plots. Forestry products are sometimes cross-cut, but longer-term studies are needed, especially in Tanzania, Zimbabwe, and Uganda. Most of the studies were focused on conservation agriculture practices without sufficient information on other greenhouse gas reduction strategies. Furthermore, there was no single study that investigated the adoption of carbon-offsetting practices.

RESEARCH METHODOLOGY

Boolean Operators, Inclusion and Exclusion Criteria, and Screening Process

This review study employed Boolean operators (AND, OR, NOT) to refine search queries across databases such as Google Scholar, Web of Science, ScienceDirect, and Scopus. The literature review was conducted using the following inclusion criteria to ensure relevance and rigour:

- Peer-reviewed studies published between 2021 and 2024: Only recent, high-quality research articles from reputable journals were considered to capture the latest advancements and findings in the field.
- Studies focusing on agroforestry and conservation agriculture as climate-smart solutions: The review prioritised research that explicitly examined agroforestry (AF) and conservation agriculture (CA) as key climate-smart agriculture (CSA) practices, emphasising their role in enhancing resilience, productivity, and sustainability in agricultural systems.
- Research conducted in Kenya, Tanzania, Uganda, and Zimbabwe: Geographic focus was limited to these four countries to ensure contextual relevance and to align with the study's objectives of understanding CSA adoption and impacts in sub-Saharan Africa.
- Articles available in English: To maintain consistency and accessibility, only studies published in English were included, ensuring that the findings could be comprehensively analysed and interpreted.

This approach ensured a focused and systematic review of the most current and applicable research, providing a robust foundation for understanding the potential and challenges of agroforestry and conservation agriculture as climate-smart solutions in the specified regions.

Exclusion criteria include:

Exclusion criteria include studies that fall outside the defined African context, ensuring that only research relevant to Kenya, Tanzania, Uganda, and Zimbabwe is considered. Additionally, research that does not explicitly discuss climate-smart agricultural practices, such as agroforestry or conservation agriculture, is excluded to maintain thematic relevance. Furthermore, non-peer-reviewed sources, including opinion pieces, blogs, and unverified reports, are omitted to ensure the credibility and reliability of the findings presented in this review.

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The screening process follows a three-stage approach:

- Title and Abstract Screening: Initial screening involved evaluating the titles and abstracts of articles to identify those aligning with the inclusion criteria, such as a focus on agroforestry, conservation agriculture, and climate-smart agriculture. Articles meeting these criteria advanced to the next stage.
- Full-Text Review: A comprehensive analysis of the full texts was conducted to assess their relevance, methodological rigour, and alignment with the study's objectives. This step ensured that only high-quality, contextually appropriate research was considered.
- Final Selection: The final stage involved selecting studies that provided substantial and actionable data on agroforestry, conservation agriculture, and their impacts on food security, productivity, and environmental sustainability. This rigorous process ensured the inclusion of the most relevant and impactful research for the review

Table 1: Included Studies

Study	Author(s)	Year	Focus Area
Global carbon sequestration potential of agroforestry	Zomer et al.	2022	Agroforestry, Carbon Sequestration
Carbon storage and economic efficiency of fruit-based systems	Singh et al.	2024	Sustainable Agriculture, Carbon Storage
Carbon sequestration potential of agroforestry systems	Ghale et al.	2022	Climate Change Mitigation
Apple-based agroforestry systems for biomass production	Zahoor et al.	2021	Food Security, Climate Change
Conservation Agriculture in Agroforestry Systems	Dev et al.	2022	Conservation Agriculture
Mitigation and Adaptation Options in Agroforestry	Gautam et al.	2022	Climate Adaptation
Nitrogen-fixing trees and organic carbon sequestration	Koutika et al.	2021	Agroforestry, Carbon Sequestration
The impact of conservation agriculture adoption on farmer welfare	Ngalande	2021	Conservation Agriculture, Welfare Impact
Impact of conservation agriculture on maize productivity	Mwiinga	2021	Conservation Agriculture, Crop Productivity
Maize yields from rotation and intercropping systems	Mupangwa et al.	2021	Conservation Agriculture, Maize Yields
Understanding adoption and impacts of conservation agriculture	Ngoma et al.	2021	Conservation Agriculture, Adoption Impact
Conservation agriculture in semi-arid Zimbabwe	Mbanyele et al.	2022	Conservation Agriculture, Soil Water Availability
Adoption of conservation agriculture in Rwanda	Murindangabo et al.	2021	Conservation Agriculture, Rwanda
Soil nutrients and crop yield response to conservation management	Kiboi et al.	2021	Soil Management, Conservation Practices
Machine learning model predicting maize yields	Muthoni et al.	2021	Machine Learning, Conservation Agriculture

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Study	Author(s)	Year	Focus Area
Agroforestry systems and soil fertility enhancement	Tsufac et al.	2021	Agroforestry, Soil Fertility
Climate change and small-scale agriculture in Africa	Apraku et al.	2021	Climate Change, Indigenous Knowledge
Climate-smart agriculture research and applications in Africa	Barasa et al.	2021	Climate-Smart Agriculture
Gender and social seed networks for climate adaptation	Otieno et al.	2021	Gender, Climate Change Adaptation
Nature-based solutions for water resource management in ASALs	Okello et al.	2024	Water Management, Nature-Based Solutions
The Impact of Climate-Smart Agriculture on Household Welfare	Mujeyi et al.	2021	Climate-Smart Agriculture, Household Welfare

RESEARCH FINDINGS

On-farm measurement of carbon stocks in agroforestry practices and conservation agriculture has demonstrated that these practices, when implemented well, can have a substantial climate change mitigation potential. In the case of agroforestry practices, the main driver of change was increased carbon stocks in the trees, typically over 50 to 100 tonnes per hectare. Key to this is, of course, the extent of agroforestry inclusion, with the potential to include all cropland areas not already used for agro-biodiversity or high-carbon landscapes of peats or wetlands (Tsufac et al., 2021; Marques et al., 2022). The height of the trees is key, as is the biophysical use of biomass and inclusion of a variety of species, so long as we understand which has the most potential. In conservation agriculture practices, increases in soil carbon stocks could reach 20 to 40 tonnes per hectare of soils that have been diminished by historic conventional farming practices. These examples will be reviewed in the main body of the report. Given these conditions, and under high-emission climates, the potential for farmlands to make a major contribution to climate mitigation, and conversely not be locked into business-as-usual emissions or conversion to biomass for increased bioenergy production, remains stark. Truly climate-smart integration for agriculture can increase a web of resources at the farm level.

Assessment of the Effectiveness of Agroforestry and Conservation Agriculture in Kenya

In Kenya, the prevalence of chronic food insecurity rose from 42% to 54% between 2008 and 2012. The rural poor, who are most involved in agriculture, are the hardest hit. Kenya relies heavily on rain-fed agriculture, with an estimated 70% of the population dependent on agriculture for their livelihoods. In Kenya, soil fertility decline and inadequate, unreliable rainfall continue to threaten food security for the majority of Kenyan households. Agriculture occupies 65% of the country, growing at a rate of 1.7% a year over the last 10 years, and shifting land use cover from indigenous and exotic forest, brushland, savanna, woodland, and grassland to largely annual and perennial crops with unplanned settlements (Muthoni et al., 2021).

Tree planting in the Kenyan highlands, home to most agriculturists and farmers who settle across considerable areas of such fertile soil, increased from 7% in 1887 to 14% in 2006. Most tree planting enthusiasm is tied to the prospect of considerable tree-based technology potential that would allow trees to help fight soil fertility decline, increase rainfall, and grow the economy. It is evident that agroforestry, the practice of farming alongside trees,

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is an ideal practice. Yet, the potential of trees to increase rainfall, buffer climate change, sustain farming-related ecosystem services, and especially to support and improve the livelihoods of the poor, alienates capricious cash crop species such as coffee, which for most of its life cycle is not food security enhancing, while thriving with rural poverty during coffee price declines.

Effectiveness of Agroforestry and Conservation Agriculture in Tanzania

In Tanzania, two separate government-established institutional frameworks manage agroforestry and conservation agriculture. The SAGCOT Centre Ltd offers a complementary platform with the MVIWATA program to promote the increase of productivity in smallholder farming using agroforestry to optimise farmland use in a way that promotes viable community tree and crop enterprises as part of sustainable agriculture intensification in selected areas. Conservation agriculture is promoted to meet the needs of more intensively cultivated land in the Kilimanjaro Region and is supported in a way that directly addresses soil erosion and conservation problems, such as the reduction of the loss of arable land, where there is the greatest concern about increasing land scarcity, the cultivation of steep slopes, and the environmental damage resulting from the conversion of forest to agricultural land (Kiboi et al., 2021). This finding, although portraying Tanzania as having an improved institutional framework in managing climate-smart agriculture practices compared to the three other countries, is deceptive. The study highlights the existence of many gaps in the sustainability and impact of agroforestry and conservation agriculture. The delineation of agroforestry and conservation agriculture institutions supports the emphasis in the literature on the significance of looking at the institutional fit in the initiative of climate-smart agriculture. The mere existence of institutional arrangements to deal with agroforestry and conservation agriculture does not negate the possibility of duplication within the institutional frameworks of agriculture, forestry, environment, and land management, among others, and a lack of a coordinated policy that can understand agroforestry and conservation agriculture approaches, origins, and terminology.

Effectiveness of Agroforestry and Conservation Agriculture in Uganda

Agricultural Production, both Conservation Agriculture and Agroforestry, are not completely new in Uganda; both have existed in traditional forms for centuries, but these forms were either not perfected or have been replaced with other traditional indigenous methods or shifted to other cropping forms. Compared to traditional Agroforestry and Conservation Agriculture, the new versions had some reduction in the complexity of traditional practices. The improvement of these old methods has increased the adoption of these practices regardless of location in Uganda. For instance, in the agriculturally relatively rich Eastern and South West regions, as well as in the Karamoja region, the practice was found (Murindangabo et al., 2021). The new Conservation Agriculture and Agroforestry practices were as successful as the traditional ones, and several elements of climate-smart agriculture were included. The most successful approach was implemented in the north of Uganda using both a political approach and a traditional approach, which sounds like the East African Agroforestry and Conservation Agriculture approach. However, the requirement to give villages ownership of the technology instead of a select group of skilled people is a wide-scale difference.

Effectiveness of Agroforestry and Conservation Agriculture in Zimbabwe

To assess the effectiveness of agroforestry and conservation agriculture practices, it was important to look at the state of adoption of the technologies in the country. A survey was carried out, and the results indicated low adoption of both conservation

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agriculture and agroforestry practices. Only 23.4% of farmers are practising agroforestry, while 25% are practising conservation agriculture. The highest proportion (32.9%) of households practised fields that had both technologies. The survey also revealed that there are forestry bylaws and traditional association rules and regulations that determine which tree species should be preserved and that can be cultivated by the different households in the rural areas. Agroforestry and conservation agriculture practices are used by a minority of households for different reasons, and the impacts thereof may not bring the desired relief in the face of climate change challenges. The study conducted found that greater benefits are achieved if the two technologies are practised together in a system (Mbanyele et al., 2022). In a study involving households practising zero tillage, direct seeding, and use of organic fertilisers, linear programming model results showed that the conservation agriculture system was the most preferred to conventional farming. The edible bean system model, which involved the planting of trees in rows, is feasible, and the cowpea system involving two trees per plot was a viable option. Subsidies on interest rates for financing farming inputs by financial institutions and promotional awareness programs were the preferred initiatives by the farmers in the study for the improvement of conservation agriculture.

DISCUSSION OF FINDINGS

Agroforestry and conservation agriculture are increasingly recognised as climate-smart farming methods due to their role in helping farmers adapt to climate change and their capacity to absorb greenhouse gases. This conclusion is drawn from a review of online literature, including studies that utilised questionnaires to gather input from smallholder farmers in Kenya, Tanzania, Uganda, and Zimbabwe. Findings from these surveys and accompanying field visits show that agroforestry is widely accepted and practised in these countries. Farmers incorporate elements such as roadside and protected trees, living hedges, fruit trees, and timber species into their farms and shifting cultivation areas, adapting their use based on local landscapes (Castle et al., 2021; Rosati et al., 2021; Adedibu, 2023).On the other hand, CA was only practised in a region across the central Kenya-Uganda plateau as an extension of large-scale commercial farming. Respondents in Zimbabwe and Tanzania either had heard of CA or were practising some of the CA principles, such as reduced tillage and using mulch on ridges in planting maize. In Uganda, some respondents only practised reduced tillage, while in Kenya, some of the respondents either practised maize bean rotation or used inorganic fertilisers on part of their farms. People practising agroforestry cite reduced loss of soil by water erosion as the main advantage of the technology, while reducing soil erosion is the main advantage, according to those practising CA (Das et al., 2022). The main concern of those practising agroforestry is that trees compete with crops for available water, as reported by 43% of the research participants. The main concern among those practising CA is that of weeds competing with crops, followed by the fact that the available mulch hinders crop germination and growth, as reported by 44% of the research participants (Mwiinga, 2021).

Adoption and Implementation of AF and CA Practices

This subsection presents the adoption patterns and processes of the implementation of agroforestry (AF) and conservation agriculture (CA). Varying adoption levels are observed between Kenya, Tanzania, Uganda, and Zimbabwe. In all four countries, less wealthy farmers, those with no or little education, and/or with depleted or degraded natural resources are less likely to adopt AF and CA practices. Studies from specific areas of Kenya, Uganda, and Zimbabwe indicate that such factors are influential. Concerning the uptake of CA, it was often the larger-scale farmers who were open to

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change and opted for a 'no-tillage' form of CA, rather than the zero-tillage technique. Finally, studies in all countries, except for Kenya, report the length of time that farmers have been practising CA (Ngoma et al., 2021).

In sub-Saharan Africa, research programs and development organisations have worked together with national implementing bodies and farmer groups to introduce AF and CA as a promotion of a permanent soil cover, and permanent organic soil fertility, and to scale up. These processes often involve training or learning components. The studies assessed how well AF was understood in context and the degree to which it was being put into practice. In Tanzania, one study found that about 55% of the 123 households interviewed stated that they were practising woodland management, and approximately 47% could identify a range of reforestation and reforestation practices as being 'ongoing'. Only 14% of those interviewed were practising a method being advocated through the promotion of CS rice paddies in northern Tanzania. In Kenya, in Uganda (a study based on two field sites and other background studies), examine the implementation of CA practices on key Kenyan farm case studies to detail the results of adopting CA (Mupangwa et al., 2021).

Perceived Benefits and Limitations of AF and CA Practices

Perceived benefits and limitations of AF and CA practices sub-themes: Perceived benefits of Conservation Agriculture and Agroforestry; Perceived limitations of Conservation Agriculture and Agroforestry. Participants reported increased agricultural yields, improved soil fertility and integrity, and enhanced resilience to erratic weather and climate change as benefits linked to both agroforestry (AF) and conservation agriculture (CA) in Kenya, Tanzania, Uganda, and Zimbabwe. Some specifically mentioned farmers had-no-rain or zai/pit planting as forms of CA as food/feed sources being especially relevant in times of scarcity (Kaur et al., 2023; Rawat et al., 2022). For example, a discussant from Kenya said, “There are several benefits of AF, that is the availability of food, reduction of drought periods, and shamba (fertile soil). The only limitation is the little rainfall that we receive in our sub-counties; therefore, rains need to improve to run bigger sizes of about 14 acres.”

The overall lack of perceived limitations offers important insight into the acceptability of and enthusiasm for the practices. Certainly, it could mean that the technologies are as effective as preservatives, promoting sustainability through their large number of perceived benefits. It is also possible that some individuals may have doubted the relevance of the question and were more focused on short-term benefits when asked about the limitations of the practices. Some findings in the CA literature have found that the practices can be inflexible, not easily adaptable to shifting climatic conditions, due to their promotion of mono-cropping and therefore not yet suitable as CSA practices. Moreover, all of the perceived limitations are possible implications that need to be considered when advocating for AF and CA on a wider geographical basis than farmers using the practices described in these papers reside.

Factors Influencing the Adoption and Effectiveness of AF and CA Practices

This subsection reviews the factors associated with an increase in the adoption and effectiveness of agroforestry and conservation agriculture practices in Africa. The assessment identified several issues. Economically, farmers must have access to credit and market opportunities to cover the costs of transitioning to conservation agriculture or agroforestry and a low-risk environment for investment in such practices. At the community level, individual farmers may feel there is a need to comply with established community norms regarding the type of crops and the overall management of crops that are grown in a locality.

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Thus, social capital building and collective action addressing specific issues such as water access may be helpful. Many of the farmers interviewed indicated that they produce 'enough' food for their own needs and those of their families. To encourage the commercialisation of agroforestry and conservation agriculture, such farmers need to be made more aware of the need and potential benefits (Fatima et al., 2024; Pantera et al., 2021).

Many uneducated farmers are more likely to use their limited resources on activities where they know that, in the end, they will have food for themselves and their families. An enormous amount of extension work will therefore be needed to change the attitudes and practices of these and more progressive farmers who are concerned about increasing their primary production. These issues affect the feasibility as well as the impact of scaling up agroforestry-conservation agriculture practices in Malawi (Udawatta et al., 2021; Jose & Udawatta, 2021). Environmentally, the availability of water, good water management, and low annual rainfall may increase the need for such practices. In Zimbabwe, the kinds of outputs of agroforestry stands were significantly affected by whether and which household members practised conservation agriculture. Note that in the same regions of the same household in Mutoko and Lupane, conservation agriculture was also practised.

Comparison of the Effectiveness of AF and CA Practices in Different Contexts

A comparison of the effectiveness of AF and CA practices in different contexts shows that agricultural systems respond differently to AF and CA. Crop yield responses and ecosystem services directly related to crop production are detailed from all case study countries; qualitative responses and farmer satisfaction are detailed from Kenya, Uganda, and Zimbabwe. The results are mixed in terms of yield responses: some countries and sites have shown clear improvements in crop yields, while others show only small, sporadic, or areas of loss. More universally, positive responses to better soil quality and increased biomass are noted, although Kenyan and Ugandan sites lack clear responses for some of these components. Notably, the Ugandan case studies show increased landslides, yet other sites lack data on potential negative trade-offs (Rodenburg et al., 2021; Mazhar et al., 2021). None of the case studies detailed the role of either AF or CA in reducing harmful emissions; thus, we are not able to compare outcomes across countries.

By application of different principles in AF and CA and by using tailored intervention packages, the effectiveness of both practices varies across different socio-geographical contexts. There is no single measure of the 'success' of AF or CA systems, and what is 'best practice'—indeed, whether AF or CA are successful—will be different depending on what is assessed and where. Each of the studies has areas of success, which demonstrate the best to meet many different criteria; the main differences between the case studies are determined by ecological and socio-economic factors, best suited to different technical practices. Key lessons can be noted across the case studies, which include the value of micro-adaptation, the compatibility of different interventions, and the need to build on existing agricultural solutions. All case studies also show the importance of regular evaluation and updating to create successful climate-smart agricultural practices that allow farmers to face multiple challenges.

Implications of the Study Findings for Policy, Practice, and Future Research

The results of this study point to a need to look at the design and implementation process of climate-smart agriculture policy intervention. The research findings indicate that it remains important to explore contextual factors that might interact with climate-smart agriculture policy intervention in new ways. It is also important to develop a comprehensive

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framework to inform decision-making about context applicability (Santiago-Freijanes et al., 2021; Rosati et al., 2021). Few adaptations or mitigation agriculture policy options integrate questions on improved understanding of adaptation and mitigation practices, their environmental effects, or interactivity in a complex and uncertain policy environment. These research findings underline the importance of a better understanding of the current marginalisation as well as potential opportunities. A particular focus on differences or similarities in adoption and capacity for agricultural transformation can help uncover how collective societal action within an agricultural system can help enhance transformative agencies in agriculture.

A collective action perspective will be necessary for future research to study and capacitate the societal linkages and clashing interests, trade-offs, and tensions in enhancing rural livelihoods. Future research could investigate what potential there is for different governance arrangements in farming communities, in regions, or at national levels to allocate costs and benefits of radical or gradual changes in land use. The results of this study suggest that considerable differences exist between sustainability outcomes in agriculture. Nevertheless, these different aggregated climate-smart agriculture practices may have different advantages and trade-offs between various sectors and across different levels of community administration and ecological scales. This would show the political feasibility and effectiveness of the various contexts in which climate-smart agriculture may be able to foster transformative agency (Koutika et al., 2021; Fahad et al., 2022). The present study addresses many of the typical shortcomings of farm survey research and provides policy-relevant insights for seven districts. However, some limitations related to the study area and the way the study was carried out limit the interpretation of the results.

Comparison with Existing Literature and Studies

Most of the studies that have gone on to understand which type of interventions are perceived by farmers to be climate-smart agriculture (CSA) have focused on the aggregate notion of CSA. Thus, little is known about whether agroforestry or conservation agriculture practices have the attributes of being classified under different axes of CSA, that is, increasing resilience, promoting food security, and reducing greenhouse gas emissions (Reicosky & Kassam, 2021; Cárceles et al., 2022). This study also observed that, although farmers recognise certain practices to be CSA, they said that the Productive Safety Net Program does not deliver to them. Trade-offs and synergies among axes of CSA are likely to be differential across locations and farm households. CSA practices can exist, but their main attribute could be climate change adaptive capacity in some locations, while in others, they might have mitigation potential, and in others, they might have a direct effect on food security. Coexistence of an overlap in win-win, win-lose, and lose-lose practices is possible (Bohoussou et al., 2022; Francaviglia et al., 2023).

Based on the different characteristics of different axes of CSA, the set of practices that are perceived to be CSA and those that are not, and when perceived to be so under one axis and not the other, should be different. These win-win agricultural development projects aim to bring development dividends that are economic, social, and environmental for the poor and naturally use CSA-like interventions to do so.

SUMMARY OF THE MAIN FINDINGS

A study conducted in Kenya, Tanzania, Uganda, and Zimbabwe in 2017 examined barriers to adopting agroforestry (AF) and conservation agriculture (CA) for climate resilience in sub-Saharan Africa. Adoption rates varied, with Uganda reaching 75%

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and Kenya at 35%. The primary motivation for adoption was improved soil fertility and yields. However, most who discontinued these practices did so within the first year due to the high cost of farm inputs.

The study highlighted key factors that could enhance adoption, such as minimising quality and quantity risks, promoting improved germplasm, ensuring better animal feed control during different seasons, diversifying agricultural systems, and intensifying production. The most significant barrier to effectiveness was the harsh environment and marginal lands, followed by financial constraints, limited awareness, water scarcity, and restricted land ownership by women and youth. The findings did not align with the initial conceptual framework developed for the research.

Across the four countries, farmers viewed these practices as a mix of conventional and ecological techniques, such as minimum tillage. Challenges identified included biophysical factors like soil and water quality, as well as social factors such as misconceptions about these technologies, lack of awareness and training, insufficient extension services, outdated agricultural information, reliance on rain-fed agriculture, land tenure issues, and limited governmental support. The study found that social factors, rather than biophysical or personal constraints, were the primary obstacles to adoption. Although financial limitations, farm input shortages, and weather conditions were concerns, social barriers were more prominent.

While tailored for Kenya, the study's insights have broader implications for Uganda, Tanzania, and Zimbabwe. The primary goal of promoting AF and CA as climate-smart agriculture (CSA) practices is to enhance smallholder resilience to climate shocks and reduce greenhouse gas emissions through improved resource management. Expansion trends in AF indicate potential benefits for food security and climate adaptation, especially in Uganda and Zimbabwe. In Zimbabwe, CA practices have improved yields and reduced input reliance. In Tanzania, better-resourced farmers have successfully commercialised CA practices alongside diversified crop-livestock farming, aligning agroforestry with commercial agriculture. Tree-based practices were often retained as a fallback during adverse conditions.

Despite some positive outcomes, de-adoption, fragmented implementation, and diversified use of AF and CA were common across the study sites. This pattern reflects farmers' adaptive responses to climate uncertainty, not only through mixed CA and AF practices but also through income diversification, including occasional de-adoption of AF in favour of agrochemical use in different seasons. A flexible portfolio approach could enhance AF's benefits, though tensions may arise between farmers, policymakers, and other stakeholders regarding climate-smart agricultural development.

The findings suggest that continuous stakeholder collaboration is essential to align AF and CA practices with farmers' needs and perceptions. Co-learning, knowledge exchange, and stakeholder engagement should be central to building trust among governments, civil society, and farmers. An integrated development approach and evidence-based agricultural policymaking will be crucial to ensuring the sustainable adoption and effectiveness of these climate resilience strategies.

CONCLUSION

This study highlights the potential of agroforestry (AF) and conservation agriculture (CA) as climate-smart agriculture (CSA) practices to enhance food security, improve soil health, and build climate resilience among smallholder farmers in Kenya, Tanzania, Uganda, and Zimbabwe. While AF and CA demonstrate significant benefits, such as increased carbon sequestration, improved soil fertility, and enhanced crop yields, their adoption remains limited due to financial constraints, limited access to credit, and socio-economic disparities. Mixed results in crop productivity and inconsistent adoption rates underscore the need for context-specific interventions tailored to local conditions. The findings emphasise the importance of integrating innovative techniques with traditional practices, leveraging organic matter as a key driver of soil health, and addressing systemic barriers to adoption. Supportive policies, institutional capacity-building, and targeted extension services are crucial for scaling up these practices. Additionally, monetising the benefits of AF and CA, along with establishing governance structures, could enhance adoption rates and ensure long-term sustainability. Future research should focus on refining models to increase yields on small land sizes, addressing labour constraints, and employing participatory approaches to align AF and CA practices with farmers' needs. Continuous stakeholder collaboration, knowledge exchange, and evidence-based policymaking are essential to overcoming barriers and maximising the benefits of these practices. By addressing these challenges, AF and CA can play a pivotal role in enhancing food security, improving ecosystem services, and building resilience against climate change in sub-Saharan Africa.

REFERENCES

Adedibu, P. A. (2023). Ecological problems of agriculture: impacts and sustainable solutions. ScienceOpen preprints. 10.14293/PR2199.000145.v1

Allan, R. P., Arias, P. A., Berger, S., Canadell, J. G., Cassou, C., Chen, D., & Zickfeld, K. (2023). Intergovernmental Panel on Climate Change (IPCC). Summary for Policymakers. In Climate change 2021: The physical science basis. Contribution of working group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 3-32). https://doi.org/10.1017/9781009157896.001

Apraku, A., Morton, J. F., & Gyampoh, B. A. (2021). Climate change and small-scale agriculture in Africa: Does indigenous knowledge matter? Insights from Kenya and South Africa. Scientific African. https://doi.org/10.1016/j.sciaf.2021.e00821

Arshad, A., Raza, M. A., Zhang, Y., Zhang, L., Wang, X., Ahmed, M., & Habib-ur-Rehman, M. (2021). Impact of climate warming on cotton growth and yields in China and Pakistan: A regional perspective. Agriculture, 11(2), 97. https://doi.org/10.3390/agriculture11020097

Barasa, P. M., Botai, C. M., Botai, J. O., & Mabhaudhi, T. (2021). A review of climate-smart agriculture research and applications in Africa. Agronomy. https://doi.org/10.3390/agronomy11061255

Bohoussou, Y. N. D., Kou, Y. H., Yu, W. B., Lin, B. J., Virk, A. L., Zhao, X., & Zhang, H. L. (2022). Impacts of the components of conservation agriculture on soil organic carbon and total nitrogen storage: a global meta-analysis. Science of the Total Environment, 842, 156822. https://doi.org/10.1016/j.scitotenv.2022.156822

Cárceles Rodríguez, B., Durán-Zuazo, V. H., Soriano Rodríguez, M., García-Tejero, I. F., Gálvez Ruiz, B., & Cuadros Tavira, S. (2022). Conservation agriculture as a sustainable system for soil health: A review. Soil Systems, 6(4), 87. https://doi.org/10.3390/soilsystems6040087

Castle, S. E., Miller, D. C., Ordonez, P. J., Baylis, K., & Hughes, K. (2021). The impacts of agroforestry interventions on agricultural productivity, ecosystem services, and human well‐being in low‐and middle‐income

Article DOI : https://doi.org/10.37284/eajab.8.1.2975

countries: A systematic review. Campbell Systematic Reviews, 17(2), e1167. https://doi.org/10.1002/cl2.1167

Cerca, M., Sosa, A., Gusciute, E., & Murphy, F. (2022). Strategic planning of bio-based supply chains: Unlocking bottlenecks and incorporating social sustainability into biorefinery systems. Sustainable Production and Consumption, 34, 219- 232. http://hdl.handle.net/10197/26461

Choden, T. & Ghaley, B. B. (2021). A portfolio of effective water and soil conservation practices for arable production systems in Europe and North Africa. Sustainability. https://doi.org/10.3390/su13052726

Cos, J., Doblas-Reyes, F., Jury, M., Marcos, R., Bretonnière, P. A., & Samsó, M. (2022). The Mediterranean climate change hotspot in the CMIP5 and CMIP6 projections. Earth System Dynamics, 13(1), 321-340. https://doi.org/10.5194/esd-13-321-2022

Das, S., Chatterjee, S., & Rajbanshi, J. (2022). Responses of soil organic carbon to conservation practices including climate-smart agriculture in tropical and subtropical regions: A meta-analysis. Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2021.150428

Dev, I., Ram, A., Kumar, N., Uthappa, A. R., & Arunachalam, A. (2022). Conservation Agriculture in Agroforestry Systems. In Conservation Agriculture in India (pp. 285-302). Routledge. https://doi.org/10.4324/9781003292487-17

Egli, L., Rüschhoff, J., & Priess, J. (2023). A systematic review of the ecological, social and economic sustainability effects of community-supported agriculture. Frontiers in Sustainable Food Systems. https://doi.org/10.3389/fsufs.2023.1136866

Fahad, S., Chavan, S. B., Chichaghare, A. R., Uthappa, A. R., Kumar, M., Kakade, V., & Poczai, P. (2022). Agroforestry systems for soil health improvement and maintenance. Sustainability, 14(22), 14877. https://doi.org/10.3390/su142214877

Fatima, S., Abbas, S., Rebi, A., & Ying, Z. (2024). Sustainable forestry and environmental impacts: Assessing the economic, environmental, and social benefits of adopting sustainable agricultural practices. https://doi.org/10.1016/j.ecofro.2024.05.009

Francaviglia, R., Almagro, M., & Vicente-Vicente, J. L. (2023). Conservation agriculture and soil organic carbon: Principles, processes, practices and policy options. Soil Systems. https://doi.org/10.3390/soilsystems7010017

Gautam, K., Thakur, S., Bhat, V., & Bhat, S. S. (2022). Forests and Tree-based Land Use Systems: Mitigation and Adaptation Option to Combat Climate Change. In Climate Change Alleviation for Sustainable Progression (pp. 219- 255). https://doi.org/10.1201/9781003106982-12

Ghale, B., Mitra, E., Sodhi, H. S., Verma, A. K., & Kumar, S. (2022). Carbon sequestration potential of agroforestry systems and its potential in climate change mitigation. Water, Air, & Soil Pollution, 233(7), 228. https://doi.org/10.1007/s11270-022-05689-4

Henderson, S. B., McLean, K. E., Lee, M. J., & Kosatsky, T. (2022). Analysis of community deaths during the catastrophic 2021 heat dome: Early evidence to inform the public health response during subsequent events in greater Vancouver, Canada. Environmental

Epidemiology, 6(1), e189. https://doi.org/10.1097/ee9.0000000000000189

Hermans, T. D., Dougill, A. J., Whitfield, S., Peacock, C. L., Eze, S., & Thierfelder, C. (2021). Combining local knowledge and soil science for integrated soil health assessments in conservation agriculture systems. Journal of Environmental Management, 286, 112192. https://doi.org/10.1016/j.jenvman.2021.112192

Jain, P., Castellanos-Acuna, D., Coogan, S. C., Abatzoglou, J. T., & Flannigan, M. D. (2022). Observed increases in extreme fire weather driven by atmospheric humidity and temperature. Nature Climate Change, 12(1), 63-70. http://www.nature.com/natureclimatechange

Jose, S. & Udawatta, R. P. (2021). Agroforestry for ecosystem services: An introduction. Agroforestry and Ecosystem Services. https://doi.org/10.1007/978-3-030-80060-4_1

Jose, S., Garrett, H. E. G., Gold, M. A., Lassoie, J. P., Buck, L. E., & Current, D. (2021). Agroforestry as an integrated, multifunctional land use management strategy. North American Agroforestry, 1-25. https://doi.org/10.1002/9780891183785.ch1

Jumiyati, S., & Frimawaty, E. (2024). Application of edu-agrotourism and agroforestry: patterns of land use on conservation in the buffer area. International Journal of Conservation Science, 15(1), 657-672. 10.36868/IJCS.2024.01.19

Kaur, A., Paruchuri, R. G., Nayak, P., Devi, K. B., Upadhyay, L., Kumar, A., & Yousuf, M. (2023). The role of agroforestry in soil conservation and sustainable crop production: a comprehensive review. International Journal of Environment and Climate Change, 13(11), 3089-3095. https://doi.org/10.9734/ijecc/2023/v13i113478

Keprate, A., Bhardwaj, D. R., Sharma, P., Verma, K., Abbas, G., Sharma, V., & Janju, S. (2024). Climate resilient agroforestry systems for sustainable land use and livelihood. In Transforming Agricultural Management for a Sustainable Future: Climate Change and Machine Learning Perspectives (pp. 141-161). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-63430-7_7

Kiboi, M. N., Ngetich, F. K., Mucheru-Muna, M. W., Diels, J., & Mugendi, D. N. (2021). Soil nutrients and crop yield response to conservation-effective management practices in the sub-humid highlands agro-ecologies of Kenya. Heliyon, 7(6). https://doi.org/10.1016/j.heliyon.2021.e07156

Kimathi, L. M. (2023). Impact of Conservation Agriculture on Smallholder Farmer Livelihoods in Kenya and Zimbabwe. [HTML]

Koutika, L. S., Taba, K., Ndongo, M., & Kaonga, M. (2021). Nitrogen-fixing trees increase organic carbon sequestration in forest and agroforestry ecosystems in the Congo Basin. Regional Environmental Change, 21(4), 109. https://doi.org/10.1007/s10113-021-01816-9

Kumar, M., Mitra, S., Mazumdar, S. P., Majumdar, B., Saha, A. R., Singh, S. R., & Hossain, A. (2021). Improvement of soil health and system productivity through crop diversification and residue incorporation under jute-based different cropping systems. Agronomy, 11(8), 1622. mdpi.com

Li, S., Gong, S., Hou, Y., Li, X., & Wang, C. (2022). The impacts of agroforestry on soil multi-functionality depending on practices and duration. Science of the Total Environment. [HTML]

Marques, M. A., Anjos, L. H. C. D., & Sanchez Delgado, A. R. (2022). Land recovery and soil

Article DOI : https://doi.org/10.37284/eajab.8.1.2975

management with agroforestry systems. Spanish Journal of Soil Science, 12, 10457. https://doi.org/10.3389/sjss.2022.10457

Mazhar, R., Ghafoor, A., Xuehao, B., & Wei, Z. (2021). Fostering sustainable agriculture: Do institutional factors impact the adoption of multiple climate-smart agricultural practices among new entry organic farmers in …. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2020.124620 Mbanyele, V., Mtambanengwe, F., Nezomba, H., Rurinda, J., & Mapfumo, P. (2022). Conservation agriculture in semi-arid Zimbabwe: a promising practice to improve finger millet (Eleusine coracana Gaertn.) productivity and soil water availability in the short term. Agriculture, 12(5), 622. https://doi.org/10.1016/j.jclepro.2020.14624

Mujeyi, A., Mudhara, M., & Mutenje, M. (2021). The impact of climate smart agriculture on household welfare in smallholder integrated crop–livestock farming systems: evidence from Zimbabwe. Agriculture & Food Security. https://doi.org/10.1186/s40066-020-00277-3

Mupangwa, W., Nyagumbo, I., Liben, F., Chipindu, L., Craufurd, P., & Mkuhlani, S. (2021). Maize yields from rotation and intercropping systems with different legumes under conservation agriculture in contrasting agro-ecologies. Agriculture, ecosystems & environment, 306, 107170. https://doi.org/10.1016/j.agee.2020.107170

Murindangabo, Y. T., Kopecký, M., & Konvalina, P. (2021). Adoption of conservation agriculture in Rwanda: a case study of Gicumbi District Region. Agronomy. https://doi.org/10.3390/agronomy11091732

Muthoni, F., Thierfelder, C., Mudereri, B., Manda, J., Bekunda, M., & Hoeschle-Zeledon, I. (2021, July). Machine learning model accurately predict maize grain yields in conservation agriculture systems in Southern Africa. In 2021 9th International Conference on Agro-Geoinformatics (Agro-Geoinformatics) (pp. 1-5). IEEE. https://doi.org/10.1109/agro-geoinformatics50104.2021.9530335

Mwiinga, E. (2021). Impact of conservation agriculture on maize productivity and income among smallholder farmers in selected provinces of Zambia. https://doi.org/10.5539/jas.v9n9p168

Ngalande, N. (2021). The impact of conservation agriculture adoption on farmer welfare: a comparative assessment of Zambia and Zimbabwe.

Ngoma, H., Angelsen, A., Jayne, T. S., & Chapoto, A. (2021). Understanding adoption and impacts of conservation agriculture in eastern and southern Africa: a review. Frontiers in Agronomy. https://doi.org/10.3389/fagro.2021.671690

Notaro, M., Gary, C., Le Coq, J. F., Metay, A., & Rapidel, B. (2022). How to increase the joint provision of ecosystem services by agricultural systems. Evidence from coffee-based agroforestry systems. Agricultural Systems. https://www.sciencedirect.com/science/article/pii/S0308521X21002857Okello, C., Githiora, Y. W., Sithole, S., & Owuor, M. A. (2024). Nature-based solutions for water resource management in Africa's arid and sem-arid lands (ASALs): A systematic review of existing interventions. Nature- Based Solutions.https://doi.org/10.1016/j.nbsj.2024.100172

Otieno, G., Zebrowski, W. M., Recha, J., & Reynolds, T. W. (2021). Gender and social seed networks for climate change adaptation: evidence from bean, finger millet, and sorghum seed systems in East Africa. Sustainability. https://doi.org/10.3390/su13042074

Pantera, A., Mosquera-Losada, M. R., Herzog, F., & Den Herder, M. (2021). Agroforestry and the environment. Agroforestry Systems, 95(5), 767-774. https://doi.org/10.1007/s10457-021-00640-8

Park, M. S., Baral, H., & Shin, S. (2022). Systematic approach to agroforestry policies and practices in Asia. Forests. https://doi.org/10.3390/f13050635

Raihan, A. (2023). A review of agroforestry as a sustainable and resilient agriculture. Journal of Agriculture Sustainability and Environment. researchgate.net

Rawat, D., Mukhopadhyay, D., Mishra, G., & Bijalwan, A. (2022). Soil nitrogen dynamics and management in agroforestry systems for ecological sustainability. In Land degradation neutrality: Achieving SDG 15 by forest management (pp. 381-403). Singapore: Springer Nature Singapore.https://www.researchgate.net/publication/379244601_A_review_of_agroforestry_as_a_sustainable_and_resilient_agriculture?enrichId=rgreq- b32b53f160ce14d2fb0b17c34ca994dd- XXX&enrichSource=Y292ZXJQYWdlOzM3OTI0NDYwMTtBUzoxMTQzMTI4MTIzNDkzMzUyM0AxNzEyNTE1NjU0Nzg2&el=1_x_2&_esc=publicationCoverPdf

Rehman, A., Farooq, M., Lee, D. J., & Siddique, K. H. (2022). Sustainable agricultural practices for food security and ecosystem services. Environmental Science and Pollution Research, 29(56), 84076- 84095. https://doi.org/10.1007/s11356-022-23635-z

Reicosky, D. C., & Kassam, A. (2021). Conservation Agriculture: Carbon and conservation centered foundation for sustainable production. Soil Organic Matter and Feeding the Future, 19- 64.https://doi.org/10.1201/9781003102762-2

Robert, W. & Peter, T. H. (2024). Agroforestry and sustainable development: making the connection. Developing Areas. https://doi.org/10.4324/9781003575276-55Rodenburg, J., Büchi, L., & Haggar, J. (2021). Adoption by adaptation: Moving from conservation agriculture to conservation practices. International Journal of Agricultural Sustainability, 19(5-6), 437-455. https://doi.org/10.1080/14735903.2020.1785734

Rosati, A., Borek, R., & Canali, S. (2021). Agroforestry and organic agriculture. Agroforestry Systems. https://doi.org/10.1007/s10457-020-00559-6Rozaki, Z., Rahmawati, N., Wijaya, O., Safitri, F., Senge, M., & Kamarudin, M. F. (2021). Gender perspectives on agroforestry practices in Mt. Merapi hazards and risks prone area of Indonesia. Biodiversitas Journal of Biological Diversity, 22(7). 10.13057/biodiv/d220751

Saikanth, K., Singh, B. V., Sachan, D. S., & Singh, B. (2023). Advancing sustainable agriculture: a comprehensive review for optimizing food production and environmental conservation. International Journal of Plant & Soil Science, 35(16), 417- 425. https://doi.org/10.9734/ijpss/2023/v35i163169

Santiago-Freijanes, J. J., Mosquera-Losada, M. R., Rois-Díaz, M., Ferreiro-Domínguez, N., Pantera, A., Aldrey, J. A., & Rigueiro-Rodríguez, A. (2021). Global and European policies to foster agricultural sustainability: agroforestry. Agroforestry Systems, 95(5), 775-790. https://www.researchgate.net/publication/327057274_Global_and_European_policies_to_foster_agricultural_sustainability_agroforestry?enrichId=rgreq- 432d009c6d71ea33fd3e6df260529090- XXX&enrichSource=Y292ZXJQYWdlOzMyNzA1NzI3NDtBUzo2NjAyNDc0OTY2MzQzNzFAMTUzNDQyNjY3ODU3OA

Article DOI : https://doi.org/10.37284/eajab.8.1.2975

%3D%3D&el=1_x_2&_esc=publicationCoverPdf

Shah, K. K., Modi, B., Pandey, H. P., Subedi, A., Aryal, G., Pandey, M., & Shrestha, J. (2021). Diversified crop rotation: an approach for sustainable agriculture production. Advances in Agriculture, 2021(1), 8924087. https://doi.org/10.1155/2021/8924087

Singh, M. K., Yadav, S. K., Rajput, B. S., & Sharma, P. (2024). Carbon storage and economic efficiency of fruit-based systems in a semi-arid region: a symbiotic approach for sustainable agriculture and climate resilience. Carbon Research. https://doi.org/10.1007/s44246-024-00114-3

Smith, L. G., Westaway, S., Mullender, S., Ghaley, B. B., Xu, Y., Lehmann, L. M., & Smith, J. (2022). Assessing the multidimensional elements of sustainability in European agroforestry systems. Agricultural Systems, 197, 103357. https://orcid.org/0000-0002-9898-9288,

Suárez, L. R., Salazar, J. C. S., Casanoves, F., & Bieng, M. A. N. (2021). Cacao agroforestry systems improve soil fertility: Comparison of soil properties between forest, cacao agroforestry systems, and pasture in the Colombian Amazon. Agriculture, Ecosystems & Environment, 314, 107349. https://doi.org/10.1016/j.agee.2021.107349

Tsufac, A. R., Awazi, N. P., & Yerima, B. P. K. (2021). Characterization of agroforestry systems and their effectiveness in soil fertility enhancement in the south-west region of Cameroon. Current Research in Environmental Sustainability, 3, 100024. https://doi.org/10.1016/j.crsust.2020.100024

Udawatta, R. P., Rankoth, L. M., & Jose, S. (2021). Agroforestry for biodiversity conservation. Agroforestry and ecosystem services. https://doi.org/10.1007/978-3-030-80060-4_10

Viguier, L., Cavan, N., Bockstaller, C., Cadoux, S., Corre-Hellou, G., Dubois, S., & Angevin, F. (2021). Combining diversification practices to enhance the sustainability of conventional cropping systems. European Journal of Agronomy, 127, 126279. https://doi.org/10.1016/j.eja.2021.126279

Xu, X. C., Gu, X. W., Qing, W. A. N. G., Zhao, Y. Q., & Wang, Z. K. (2021). Open pit limit optimization considering economic profit, ecological costs and social benefits. Transactions of Nonferrous Metals Society of China, 31(12), 3847-3861. 10.1016/S1003-6326(21)65769-2

Yang, X., Zhou, B., Xu, Y., & Han, Z. (2021). CMIP6 evaluation and projection of temperature and precipitation over China. Advances in Atmospheric Sciences. researchgate.net

You, Q., Cai, Z., Pepin, N., Chen, D., Ahrens, B., Jiang, Z., & Zhang, Y. (2021). Warming amplification over the Arctic Pole and Third Pole: Trends, mechanisms and consequences. Earth-Science Reviews, 217, 103625. https://doi.org/10.1016/j.earscirev.2021.103625

Zahoor, S., Dutt, V., Mughal, A. H., Pala, N. A., Qaisar, K. N., & Khan, P. A. (2021). Apple-based agroforestry systems for biomass production and carbon sequestration: implication for food security and climate change contemplates in a temperate region of Northern Himalaya, India. Agroforestry Systems, 95, 367-382. https://doi.org/10.1007/s10457-021-00593-y

Zomer, R. J., Bossio, D. A., Trabucco, A., van Noordwijk, M., & Xu, J. (2022). Global carbon sequestration potential of agroforestry and

Article DOI : https://doi.org/10.37284/eajab.8.1.2975

increased tree cover on agricultural land. Circular Agricultural Systems, 2(1), 1-10. https://doi.org/10.48130/cas-2022-0003